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New light on the old problem of lithium pre–MS depletion: models with 2D RHD convection

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ABSTRACT

The $T_{\rm eff}$ location of Pre-Main Sequence (PMS) evolutionary tracks depends on the treatment of over-adiabaticity. We present here the PMS evolutionary tracks computed by using the mixing length theory of convection (MLT) in which the $\alpha_{\rm MLT} = l/H_p$ parameter calibration is based on 2D–hydrodynamical models (Ludwig et al. 1999). These MLT–$\alpha^{\rm 2D}$ stellar models and tracks are very similar to those computed with non–grey ATLAS9 atmospheric boundary conditions and Full Spectrum of Turbulence (FST) convection model both in the atmosphere and in the interior. The comparison of the new tracks with the location on the HR diagram of pre–MS binaries is not completely satisfactory, as some binary components are located at too low $T_{\rm eff}$. Besides, the pre–MS lithium depletion in the MLT–$\alpha^{\rm 2D}$ tracks is still much larger than that expected from the observations of lithium in young open clusters. This result is similar to that of FST models. Thus, in spite of the fact that 2D RHD models should provide a better convection description than any local model, their introduction is not sufficient to reconcile theory and observations. Lithium depletion in young clusters points towards a convection efficiency which, in pre–MS, should be smaller than in the MS. The pre–MS lithium depletion decreases significantly in FST models if we reduce the solar metallicity down to the value suggested by Asplund et al. (2004), but the corresponding solar model does not reproduce the depth of the convective zone as determined by helioseismology.

Key words: stars: stellar structure; stars: convection; stars: abundances; stars: pre-main sequence

1 INTRODUCTION

The location in the Hertzsprung–Russell diagram (HRD) of Pre-Main Sequence (PMS) evolutionary tracks is very sensitive to modeling details such as opacity, atmospheric boundary conditions, rotation and convection treatment. Montalbán et al. (2004a) and D'Antona & Montalbán (2003) pointed out that, at least for $T_{\rm eff}$ down to 4000 K, the treatment of convection transport plays a role on the PMS evolutionary tracks that is much more important than the effects from recent improvements of low temperature opacities. They showed that it is the "average efficiency" of convection in the envelope which determines both, the $T_{\rm eff}$ of PMS tracks and the lithium depletion[1] during this phase of stellar evolution.

Unfortunately, the approaches traditionally used in stellar evolution to describe the heat transport by convection are quite rough. The mixing length theory (MLT, Böhm-Vitense 1958) as well as the Full Spectrum of Turbulence (FST) model (Canuto & Mazzitelli 1991; Canuto Goldman & Mazzitelli 1996) are local theories, which ignore physical processes such as convective overshoot and radiative transfer effects.

The efficiency of convection in the superadiabatic region at the top of convective stellar envelopes determines the asymptotic value of the entropy in the deep and adiabatically stratified layers and, therefore, the star radius and $T_{\rm eff}$. Any treatment of convection, adjusted to obtain the correct adiabat, will provide similar global structures. This is the base of the MLT solar calibration. Given the relationship between convective flux and over–adiabaticity in the MLT ($F_{\rm conv} \propto (\nabla - \nabla_{\rm ad})^{3/2}\alpha^2_{\rm MLT}$), increasing the value of the $\alpha_{\rm MLT}$ parameter we decrease the value of the over-adiabaticity, and the radius decreases.

The only parameter in the MLT, $\alpha_{\rm MLT}$, is tuned to re-

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[1] This conclusion is valid only if no other transport process different than convection occurs during the PMS.

produce the solar radius at the solar age. This method has provided very good results, in spite of its simplicity. Nevertheless, the Sun yields only one calibration value, and no physical principle guarantees this value to be appropriate for the whole HR diagram, or the whole stellar structure.

The mass of the stellar convective envelope increases with decreasing $T_{\rm eff}$, and its top gradually shifts towards larger depths, so that the structure of the surface layers is less and less affected by convection as $T_{\rm eff}$ decreases. For temperatures lower than 4700 K, however, the convection zone rises again due to H_2 dissociation. Furthermore, as gravity decreases, the convective flux decreases because of the lower density, and therefore, the over-adiabatic region is more and more extended in the stellar atmosphere. Specific atmosphere models with an adequate treatment of radiation and convection transports are hence mandatory.

The available grids of model atmospheres for general use of stellar structure (ATLAS9 by Kurucz 1993 and NextGen by Hauschildt et al. 1999) were generally computed just for one specific convection model, e.g. a given $\alpha_{\rm MLT} = \alpha_{\rm MLT}^{\rm atm}$ value in the MLT. Hence, in the solar calibration, only the MLT parameter used in the interior can be changed. Montalbán et al. (2004a) showed that this kind of procedure can lead to an uncertainty of the order of 200 K in the 1 $M_\odot$ PMS track (without changing the effective temperature of MS), since its $T_{\rm eff}$ depends on the optical depth chosen to match the interior and the atmosphere models. On the other hand, Heiter et al. (2002) computed FST ATLAS9 models with a value of the $\alpha_{\rm FST}$ parameter fixed by a grey FST solar calibration. A non–grey FST solar calibration requires a larger value of $\alpha_{\rm FST}$ (0.18 in the atmosphere and in the interior –Ventura, private communication). Nevertheless, given the different properties of $\alpha_{\rm FST}$ and $\alpha_{\rm MLT}$ parameters, a discrepancy between $\alpha_{\rm FST}^{\rm atm}$ and $\alpha_{\rm FST}^{\rm in}$ have no very serious consequences on the stellar structure or on the evolutionary tracks (as shown in Montalbán et al. (2004a), this discrepancy can lead to an uncertainty in $T_{\rm eff}$–at given mass and luminosity– of the order of 2%, and <1% for 1 $M_\odot$). In any case, non–grey FST stellar models (either with $\alpha_{\rm FST}^{\rm in}$=$\alpha_{\rm FST}^{\rm atm}$, or with $\alpha_{\rm FST}^{\rm in}$=2·$\alpha_{\rm FST}^{\rm atm}$) predict a too large pre-MS lithium depletion compared to observational data in open clusters.

A more realistic approach consists in solving the hydrodynamic equations coupled to the equation of radiative transfer. Recently much progress has been made in performing 2-3D radiative–hydrodynamical (RHD) simulations of stellar surface convection (e.g. Freytag et al. 1996; Stein & Nordlund 1998; Asplund et al. 2000; Ludwig et al. 2002). These results, however, cannot be directly used in stellar evolution computations. A way of overcoming the problem of computing convection would be to have grids of 3D non local models, and, at each ($T_{\rm eff}$-gravity), calibrate the α value which provides the same specific entropy jump between the atmosphere and the adiabatic region. This procedure does not give information on the structure of the overadiabatic layers, but allows a proper computation of the interior[2].

[2] The use of an "average efficiency" of envelope convection is then useful if we wish to obtain general structural information concerning the stellar interior properties, exactly such as the lithium depletion, and the evolution of $T_{\rm eff}$ and gravity. Of course, it is less useful if we need to know the structure of the overadiabatic layers, e.g. for the computation of acoustic oscillation modes.

Extensive 3D RHD simulations for general applications to the computation of stellar evolution are not yet available, but 2D RHD simulations have been performed by Ludwig et al. (1999) for a large grid of $T_{\rm eff}$ and gravity values, and the structural information from these models has been translated into an effective mixing-length parameter $\alpha_{\rm MLT}^{\rm 2D}$, suitable to construct standard stellar structure models.

As the results from RHD models are in principle more reliable than the local models, we computed pre–MS and MS evolution, based on Ludwig et al. (1999), for masses from 0.8 to 1.5 $M_\odot$. We compare the resulting evolutionary tracks and Li abundance with those from recent local models (Montalbán et al. 2004a), which assume FST convection both in the non–grey atmosphere and in the envelope structure.

The application of 3D RHD atmosphere computation to studies of spectral line formation, have also shown that in many cases standard 1D analyses are very misleading in terms of derived element abundances (Asplund 2005). In particular, 3D computations together with a much more accurate analysis of solar spectrum and a non-LTE treatment, led to a drastic revision of the photospheric solar composition. Asplund et al. (2004 and 2005) analysis results in a significant reduction of solar metallicity down to $Z/X \sim 0.017 - 0.018$. We expect that a smaller lithium depletion could be obtained if we revise downward the solar metallicity. Unfortunately, the 2D RHD models by Ludwig et al. (1999), and the corresponding $\alpha_{\rm MLT}^{\rm 2D}$ calibration, are only available for the higher "old" solar metallicity and helium mass fraction Y=0.28. As we show in section 3 that FST and MLT–$\alpha^{\rm 2D}$ results are very similar for the standard "old" solar metallicity, we compute FST pre–MS tracks with the scaled down metal abundances, to test if the new abundances could solve the problem of PMS-lithium depletion in young open clusters.

2 "AVERAGE EFFICIENCY" OF CONVECTION FOR PRE–MS MODELS

Ludwig et al. (1999), by using their 2D RHD atmosphere models, provided a calibration of the $\alpha_{\rm MLT}$ parameter as a function of $T_{\rm eff}$ and $\log g$ in the domain $T_{\rm eff} = 4300 - 7100$ K, $\log g = 2.54 - 4.74$. We would like to stress two interesting aspects of this calibration in the PMS evolution context: first, the 2D models indicate that convection is on average 'efficient' in the atmosphere and the envelope, corresponding to a large $\alpha_{\rm MLT}$ value; and, second, $\alpha_{\rm MLT}$ increases as $T_{\rm eff}$ decreases. The $\alpha_{\rm MLT}^{\rm 2D}$ behavior has been confirmed by 3D atmosphere models. Ludwig, Allard and Hauschildt (2002) find, for an M dwarf at $T_{\rm eff} = 2800$ K and $\log g = 5$, $\alpha_{\rm MLT}\simeq 2.1$, a value noticeably larger than that required for the Sun ($\alpha_{\rm MLT}\simeq 1.6$). Trampedach et al. (1999) made a similar $\alpha_{\rm MLT}^{\rm 3D}$ calibration by using 3D model atmospheres computed by means of a different code (the time–dependent, compressible, explicit, radiative-hydrodynamics code by Stein & Nordlund 1998). For the range of main sequence gravities and $\log T_{\rm eff}$=3.68–3.83, this $\alpha_{\rm MLT}^{\rm 3D}$ calibration shows the same behavior than the $\alpha_{\rm MLT}^{\rm 2D}$ one and a systematic offset, in the sense $\alpha_{\rm MLT}^{\rm 3D} > \alpha_{\rm MLT}^{\rm 2D}$. For the Sun, Ludwig et al. (1999) found than their 2D-based calibration

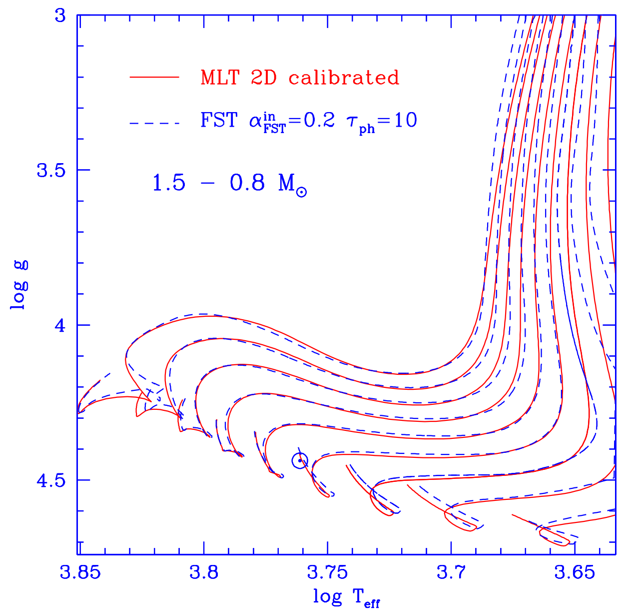

Figure 1. Evolutionary tracks using FST in the $\log T_{\rm eff}$ vs. log g plane (solid line; non–grey models with $\tau_{\rm ph}=10$ by Montalbán et al. (2004a) and 2D calibrated MLT (dashed line).

underestimates the value of $\alpha_{\rm MLT}$ by a factor ~ 0.2, and they explained that as due to a combined effect of low-temperature opacities and the 2D approximation. On the other hand, Asplund et al. (2000) have compared 2D and 3D atmosphere models for Sun, and find that the 2D solar model has marginally larger gradients than the 3D one. Ludwig et al. (1999) propose the use of a constant scaling factor to compensate the systematic offset seen in the Sun, as the relative variations of $\alpha_{\rm MLT}$ with $T_{\rm eff}$ and $\log g$ should be less affected by systematic shortcomings such as the 2D approximation.

It has also been shown that there is no unique value of the $\alpha_{\rm MLT}$ parameter that can reproduce the temperature gradients in the over-adiabatic regions (Steffen & Ludwig 1999; Trampedach 2004). Nevertheless, the function $\alpha_{\rm MLT}(T_{\rm eff},\log g)$ by Ludwig et al. (1999), guarantees that the adiabat of a stellar model, computed with this $\alpha^{\rm 2D}_{\rm MLT}$ and grey boundary conditions, provides the same adiabat (and therefore the same radius and effective temperature) as one from a complete 2D RHD computation.

An additional advantage of the procedure of computing MLT–$\alpha^{\rm 2D}$ models is that the entropy in the adiabatic convection region is independently determined and is not affected by the ambiguity and the uncertainties deriving from the use of several different physics in the over–adiabatic region of the star. So, standard non–grey MLT models are not necessarily equivalent to MLT-2D/3D ones even if the numerical value of $\alpha_{\rm MLT}$ parameter used in the stellar structure computations is in both cases the same or of the same order. We must indeed be careful when looking at the exact meaning of published results. For instance, the MLT–$\alpha^{\rm 2D}$ models will *not* be similar to the popular set of non–grey models having "$\alpha_{\rm MLT}=1.9$" by Baraffe et al. (1998). In fact, these models have indeed $\alpha_{\rm MLT}=\alpha^{\rm in}_{\rm MLT}=1.9$ in the computation of the internal structure, but the atmosphere down to $\tau_{\rm ph}=100$, i.e. to the match point with with the interior, is computed with $\alpha^{\rm atm}_{\rm MLT}=1$. It has been often pointed out that the PMS tracks by Baraffe et al. (1998) match better observations since they have lower $\rm T_{eff}$ than other computations (e.g. Hillenbrand & White 2004) and, sometimes, that has been attributed to the improved opacity in the adopted NextGen atmospheres (Allard & Hauschidt, 1997, hereinafter AH97). On the contrary, for mass values close to the solar mass, a large part of this result is simply due to the very low efficiency of convection in the most superadiabatic part of the star, namely the atmosphere down to $\tau_{\rm ph}=100$ (Montalbán et al. 2004a; D'Antona & Montalbán 2003). The calibration of $\alpha_{\rm MLT}$ in Ludwig et al. (1999), whose zero point must be obtained by reproducing the solar radius, is valid for grey models, so the same $\alpha_{\rm MLT}$ value is used in the whole structure, and the results are less ambiguous and easier to be interpreted.

3 MLT–$\alpha^{\rm 2D}$ MODELS

The MLT–$\alpha^{\rm 2D}$ stellar models have been computed with the code ATON2.0 (Ventura et al. 1998a), with grey boundary conditions, and the MLT option for convection. Ludwig et al. (1999) suggest, in the context of stellar evolutionary models, to calibrate $\alpha^0_{\rm MLT}$ with the present Sun, and to use its ratio to $\alpha^{\rm 2D}_{\rm MLT}(\odot)$ as scaling factor for the function $\alpha^{\rm 2D}_{\rm MLT}(T_{\rm eff},\log g)$. So, we used the value $\alpha^0_{\rm MLT}=1.6$ (obtained from the grey MLT Sun calibration with ATON2.0) to scale the analytical fits of $\alpha_{\rm MLT}(T_{\rm eff},\log g)$ by Ludwig et al. (1999). These "solar-calibrated" analytical fits were introduced in ATON2.0 to allow for a continuous variation of the $\alpha_{\rm MLT}$ parameter as the star evolves in the HR diagram.

The adopted helium mass fraction is Y=0.28 and the metal mass fraction is Z=0.02. The other physical inputs are the same as in Montalbán et al. (2004a)[3]. In Fig. 1 we superimpose the MLT–$\alpha^{\rm 2D}$ tracks (dashed–lines) and the non–grey FST models by Montalbán et al. (2004a) in the plane log g vs. $T_{\rm eff}$. The latter tracks are computed by using the Heiter et al. (2002) boundary conditions, and adopt FST convection, both in the atmosphere and in the interior. The two sets of results, in the range $0.8-1.5M_\odot$ are very similar. Since stellar radii (and therefore the $T_{\rm eff}$'s) are determined by the efficiency of convection in the over-adiabatic region, we can conclude that the global efficiency of convection in MLT–$\alpha^{\rm 2D}$ and FST models is very similar. This allows the use of FST models as proxies of 2D RHD models, also for different chemistry. So, we have computed low metallicity FST models with chemical and convection parameters given by the new solar calibration, that is: Y=0.2495, Z=0.01305 and the FST $\alpha_{\rm FST}$ parameter equal to 0.117.

3.1 Pre–MS Lithium depletion in MLT–$\alpha^{\rm 2D}$ models

Lithium is a light element that is burned by the nuclear reaction $^7{\rm Li}(p,^4{\rm He})^4{\rm He}$ at a relatively low temperature ($\rm T_{Li}\sim 2.5\,10^6$ K). The PMS lithium depletion rate

[3] The solar mixture used in the opacity and equation of state tables is that from Grevesse & Noels 1993

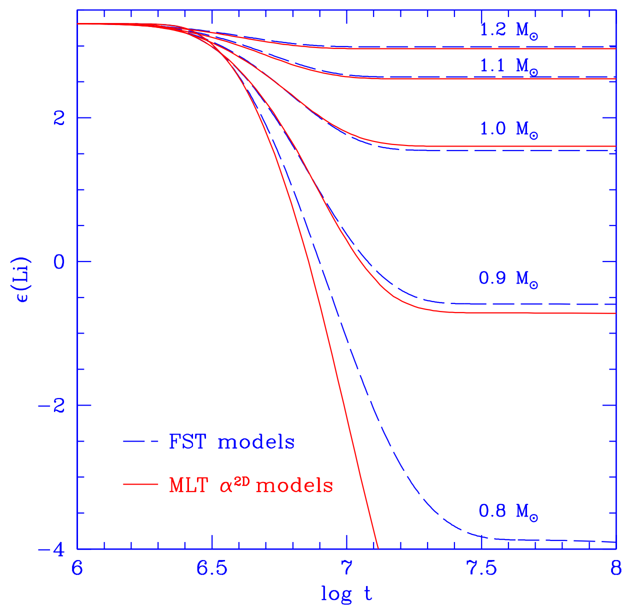

Figure 2. Lithium evolution for models computed with 2Dα calibrated MLT (solid lines) and complete (non grey) FST models (dashed lines)

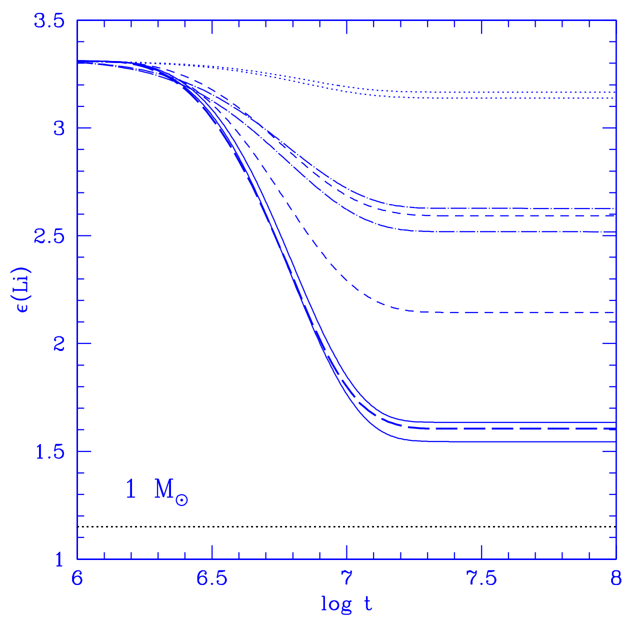

Figure 3. Lithium evolution for the solar mass with different assumptions about convection and model atmospheres. The dotted line at bottom represents today's solar lithium abundance. MLT models with AH97 model atmospheres down to $\tau_{\rm ph}=10$ and 100 are shown dotted for $\alpha_{\rm in}=1$ and dash– dotted for $\alpha_{\rm in}=1.9$. The Montalbán et al. (2004a) MLT models with Heiter et al. (2002) atmospheres down to $\tau_{\rm ph}=10$ (lower) and 100 (upper) are dashed; The continuous lines show the non–grey FST models for $\tau_{\rm ph}=10$ and 100, and, in between, the long dashed line shows the MLT–$\alpha^{\rm 2D}$ model.

strongly depends on temperature and density at the bottom of the convective region. Lithium abundances detected in young open clusters, such as the Pleiades and αPer (e.g. Soderblom et al. 1993), indicate that solar mass stars do not deplete a significant fraction lithium during their PMS. That implies structures of these stars with a temperature at the base of their convective envelope smaller than $\rm T_{Li}$.

It is generally accepted (Gough & Weiss 1976; Christensen-Darlsgaard 1997) that the overall late-type stars structure does not depend on the details of the treatment of over-adiabatic regions. Hence, the radius is determined by the value of the entropy jump between the photosphere and the deep adiabatic regions. Christensen-Dalsgaard (1997) pointed out that, for the Sun, the depth of the convective zone is almost insensitive to changes in the adiabat of the convective zone, and that the changes in the surface radius are due only to the changes of the radius of the bottom of the convective zone. He also pointed out that the same should probably occur for other stars, if the derivatives of opacity with respect to temperature and density are of the same order than in the Sun. The similarity between FST and MLT–$\alpha^{\rm 2D}$–track locations suggests that the "average efficiency" of convection is quite close in both series of models, and hence we expect that also the lithium depletion in the MLT–$\alpha^{\rm 2D}$ models should be similar to that of the FST ones. In Fig. 2 we plot the lithium depletion as a function of time for masses between 0.8 and 1.2 $M_\odot$. In these computations the initial lithium abundance was taken as log N(Li)=3.31, i.e. the solar system abundance given by Anders & Grevesse (1989)[4]. Both the MLT–$\alpha^{\rm 2D}$ models and the non–grey FST models show a depletion of the order of $\sim$ 1.7 dex for the 1 $M_\odot$ evolutionary track. Thus the non–grey FST models provide a description of the stellar structure very similar to the RHD 2D models, also with respect to lithium depletion.

Generally, local convection models are calibrated by requiring that the free parameter(s) reproduces the solar radius at the solar age. The MLT models satisfying this constraint predict, however, a pre–MS lithium depletion which is not compatible with that observed in young open clusters (D'Antona & Montalbán 2003). In Fig. 3 we plot the lithium vs. time evolution in some $1M_\odot$ models by Montalbán et al. (2004a) and in the MLT–$\alpha^{\rm 2D}$ models. As D'Antona & Montalbán (2003) remarked, the models adopting AH97 atmospheres and $\alpha^{\rm in}_{\rm MLT}$=1 deplete lithium in pre–MS by only 0.15 dex. The same models with $\alpha^{\rm in}_{\rm MLT}$=1.9 deplete 0.7 dex if the matching point is $\tau_{\rm ph}$=100, but more than 1 dex for $\tau_{\rm ph}$=10. We stress again that this result is only due to the use of a **less efficient convection** when the match with the atmosphere ($\alpha^{\rm atm}_{\rm MLT}$=1) is done at $\tau_{\rm ph}$=100, even if the $\alpha_{\rm MLT}$ parameter chosen for the interior, in order to fit the solar radius, is much larger (for instance 1.9). As it was shown in Montalbán et al. (2004a) and recalled in Sect. 1, the choice of the optical depth at which we match the two parts of the stellar structure, is not without consequences. It implies an uncertainty of almost 200 K for the

[4] The current adopted value for the meteoritic Li abundance is 3.25 ± 0.06 (Asplund et al. 2005b), but the small difference with respect to Anders & Grevesse (1990) does not significantly affect our results

$T_{\rm eff}$ of 1 $M_\odot$ PMS. *The optical depth at which the external layers change from adiabatic to over-adiabatic stratification depends on* $T_{\rm eff}$*,* $\log g$*, and chemical composition as well. To match an* $\alpha_{\rm MLT} = 1$ *structure with an* $\alpha_{\rm MLT}$*=1.9 one at fixed* $\tau_{\rm ph}$ *along the whole evolution is equivalent to decrease the average efficiency of convection in a complicate, hidden and unjustified way.*

Li abundance in young clusters suggests that, if no other physical process is affecting the location of the base of the convective zone, the PMS-tracks should be cooler than solar calibrated convection predicts. This evidence should be used to look for the shortcomings of our stellar models.

3.2 Pre–MS binaries

The location of pre–MS binaries in the HR diagram is a powerful way of constraining stellar models, but unfortunately its indications are, by now, still ambiguous, because of the dearth of systems with well known masses and and good atmospheric parameters. For some of these binaries, the location is consistent with models having high convection efficiency, but for others this is not the case. In Figure 4 we compare the MLT–$\alpha^{\rm 2D}$ tracks with the parameters derived from the observations of four binary systems: RXJ 0529.4+0041 (according to the most recent determination by Covino et al. (2004)), V1174 Ori (Stassun et al. 2004), NTT 045251+3016 (Steffen et al. 2001) and HD 98800 B (Boden et al. 2005). A detailed analysis is out of the scope of this paper, but it is evident that the agreement is reasonably good for most of the primaries but much less satisfactory for the secondary, i.e. less massive, components. The V1174 Ori primary mass ($1M_\odot$) is consistent with the corresponding MLT–$\alpha^{\rm 2D}$ track, as well as the primary masses of RXJ 0529.4+0041 ($1.3M_\odot$) and HD 98800 B ($0.699M_\odot$), but that of NTT 045251+3016 is rather different from the expected value ($1.45\pm0.19M_\odot$) is [5]. Besides, at least two secondaries seem to be too cool for the MLT–$\alpha^{\rm 2D}$ tracks, and one could perhaps guess a systematic behavior, in the sense that the low mass PMS stars seem to be cooler and to have a larger than expected radius.

This recalls what happens for the few known late–type low–mass MS binary components. High quality observations (eclipsing binaries and/or interferometric measurements) revealed a meaningful discrepancy between stellar parameters derived from observations and those based on theoretical models: the theoretical stellar radii seem to be be underestimated by 10-20%, and the effective temperatures overestimated by 5% (200 K) (e.g. Ribas 2006; Torres et al. 2005; and references therein). An accepted, but not definitely proved, explanation is that these larger than expected stellar radii are related to stellar activity. In fact, the magnetic fields associated with stellar activity can decrease the efficiency of convection (Gough & Tayler 1966; Stein et al. 1992 and references therein) and as a consequence the stellar radius must grow to transport the same quantity of energy. Besides, the decrease in effective temperature could be due

[5] the same Steffen et al. (2001) remark that the location of the primary in this system is 3σ away from the D'Antona & Mazzitelli (1994) grey–FST tracks, which are hotter than the MLT–$\alpha^{\rm 2D}$ tracks by ~270 K.

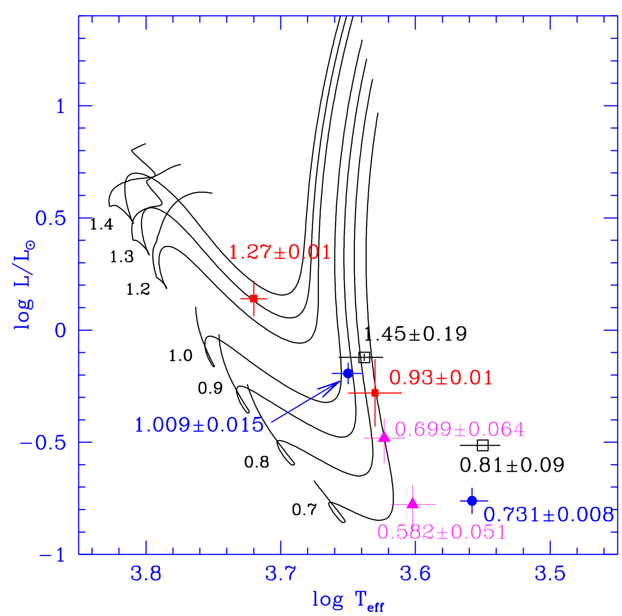

Figure 4. The location in the HR diagram of the MLT–$\alpha^{\rm 2D}$ tracks is shown together with four binaries with well determined masses, labeled in the figure. Full squares (red): RXJ 0529.4+0041 (Covino et al. 2004); full circles (blue): V1174 Ori (Stassun et al. 2004); open squares (black): NTT 045251+3016 (Steffen et al. 2001); full triangles (magenta): HD 98800 B (Boden et al. 2005)

to spots on the stellar surface. In a very recent paper, Torres et al. (2005) have shown that the discrepancy between theory and observation can also appear for stars quite similar to the Sun. In their study of the eclipsing binary V1061 Cygni with $M_{\rm Aa} = 1.282M_\odot$ and $M_{\rm Ab} = 0.9315M_\odot$, they conclude: *"Current stellar evolution models that use a mixing length parameter* α_{ML} *appropriate for the Sun agree well with the properties of the primary, but show a very large divergence in the radius of the secondary, in the sense that the predicted values are ~ 10% smaller than observed. In addition, the temperature is cooler than predicted by some 200 K ... for a star only 7% less massive than the Sun".* They suggest that there must be a relation among activity level, decrease of $T_{\rm eff}$ and underestimation of the stellar radii by the standard stellar models (calibrated by matching the Sun).

4 FST MODELS WITH REVISED SOLAR METALLICITY

We have considered, until now, MLT–$\alpha^{\rm 2D}$ models computed for the "standard" solar metallicity Z=0.02, but what will happen if we decrease Z to ~0.013, as suggested by the re–analysis of the solar spectrum by Asplund et al. (2004)? The lithium depletion would probably be reduced, without affecting too much the pre–MS tracks location, as we still must calibrate convection in order to reproduce the solar location. RHD 2D models are not available for this revised metallicity, nevertheless, we can compute models with FST convection, and make the hypothesis that, for the reduced solar metallicity, they provide similar results to MLT–$\alpha^{\rm 2D}$

models, as they do for the standard solar metallicity. In fact, the effective temperature in the Hayashi track corresponding to the solar model, calibrated with the new solar metallicity, is only 0.3% lower than that for the standard solar metallicity. However, the temperature and density at the bottom of the convective zone of these PMS models, have changed by 6 and 12 % respectively. As a consequence, lithium has been depleted only by 0.5 dex. We recall, however, that the solar model with new solar metallicity is not able to fit either the depth of the convective zone, or the sound speed profile inside the Sun.

Since the new solar abundances were published, several teams tried to recover the good match between the helioseismic Sun and the standard solar model. They proposed to increase the opacity, the microscopic diffusion coefficients, or a combination of both (e.g. Basu & Antia 2004, Montalbán et al. 2004b, Guzik et al. 2005). We recall, that none of the proposed solutions is fully satisfactory. Nevertheless, for what concerns the lithium problem, whatever solution be adopted, it should be able to change the bottom of the convective zone during MS without changing the PMS models. If the discrepancy between the standard solar model and helioseismology could be solved only changing the microscopic diffusion (not reliable at the moment, see for instance Guzik et al. 2005), since this process is very slow, perhaps we could keep a low lithium depletion. For other processes, we should justify why they work during MS and not during solar PMS. Basu & Antia (2005) and Bahcall et al. (2005) proposed the solution of increasing the Ne abundance (not directly observed in the solar spectrum) by a factor ~ 3.5. This suggestion has been supported by Drake & Testa (2005) which, on the basis of Ne abundance determination in active stars, argue that the solar Ne could be 2.5 times larger than the value adopted for the solar mixtures. Without entering in the controversy about these new Ne abundance determination (see e.g. Schmelz et al. 2005; Young 2005; Asplund et al. 2005c), we would like to recall that Ne is, with O, one of the main contributors to opacity at the bottom of the solar convective zone (close to $T_{\rm Li}$). The solution proposed by Basu & Antia (2005) implies to increase the opacity by replacing the decrease of O abundance in the new solar mixture (Asplund et al. 2004) by the increase of Ne one. A direct comparison between OPAL opacity tables, with GN93 mixture, and a solar mixture with Ne increased by a factor 3.5 yields that the opacity from this latter table, for the temperature and density typical of PMS stars, is even larger than for GN93 mixture. As a consequence, one can predict a deeper convective region in the PMS and, therefore, a lithium depletion even larger than in the "old" standard solar model.

5 CONCLUSIONS

The computation of MLT pre–MS tracks in which the $\alpha_{\rm MLT}$ parameter is calibrated on 2D RHD models (MLT–$\alpha^{\rm 2D}$ tracks) shows that these tracks deplete too much lithium, at variance with the observations of stars in young open clusters. The MLT–$\alpha^{\rm 2D}$ tracks are similar, in HR diagram location and lithium depletion, to the FST non–grey tracks by Montalbán et al. (2004a). Thus we compute FST non–grey models, correponding to the new solar metallicity determined by Asplund et al. (2004), as proxies of possible 2D RHD models for the reduced solar metallicity. The lithium depletion in 1 $M_\odot$ model has been reduced from 1.7 dex (with the "old" solar metallicity) to ~ 0.5 dex. We know, however, that such a low metalllicity is not able to reproduce other, well established, properties of the Sun. Hence, much more work shall be done, analyzing all the consequences of the new solar metallicity, before adopting the new abundances as solution of the Li problem.

The problem of lithium is therefore not solved in the framework of the numerical simulations of convection. On the contrary, 2D and 3D numerical simulations imply even more efficient convection in the PMS, while lithium depletion in young clusters and PMS binaries studied here suggest a lower efficiency. We conclude that convection in pre–MS must be less efficient than what is suggested by 2D RHD models. It is still possible that the description of pre–MS convection requires the introduction of a second parameter –linked to the stellar rotation and magnetic field, as we have suggested in the past (Ventura et al. 1998b; D'Antona et al. 2000).

The data on masses and radii coming from high quality observations of eclipsing binaries and/or interferometry of late type stars agree only in part with the MLT–$\alpha^{\rm 2D}$ models. So, while some observations (stellar parameters of binaries and lithium abundances in young clusters) require a low efficiency of convection in the late-type domain of the HR diagram, numerical simulations of convection (Ludwig et al. 1999; Trampedach et al. 1999; Ludwig et al. 2000) show the opposite: an equivalent value of the $\alpha_{\rm MLT}$ parameter that increases as effective temperature decreases.

The abovementioned observational results, together with the high activity level that PMS-stars can show (see e.g. Tayler 1987), seems to support the suggestion that that other physical processes (rotation, magnetic fields) affect the efficiency of convection in late type stars.

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